Closed-Circuit Escape Respirators (CCER)
Proposed Concepts

Disclaimer: These concepts are being presented for discussion purposes only and do not represent any final determination or policy of the agency.

Marriott Key Bridge
Arlington, VA
September 19, 2006

Agenda

Time	Topic	Presenter
9:00 a.m.	Welcome/Opening Remarks	Les Boord, NIOSH
9:45 a.m.	History/Background of SCSRs	John Kovac, NIOSH
10:30 a.m.	Break	
10:45 a.m.	Proposed Concepts	Tim Rehak/Bob Stein, NIOSH
12:30 p.m.	Lunch	
1:30 p.m.	Presentation on SCSR Research	Dr. Art Johnson, Univ. of Maryland
2:15 p.m.	Outside Speakers	
2: 45 p.m.	Break	
3:00 p.m.	Comments	
4:00 p.m.	Adjourn	

Administrative Details

- **Meeting Logistics**
  - Sign In Sheets
  - Meeting Recorded, Transcribed for Docket
  - Presentation in accordance with the Agenda
  - Q & A Period After Presentations
  - Who / Organization / Comment @ Microphone

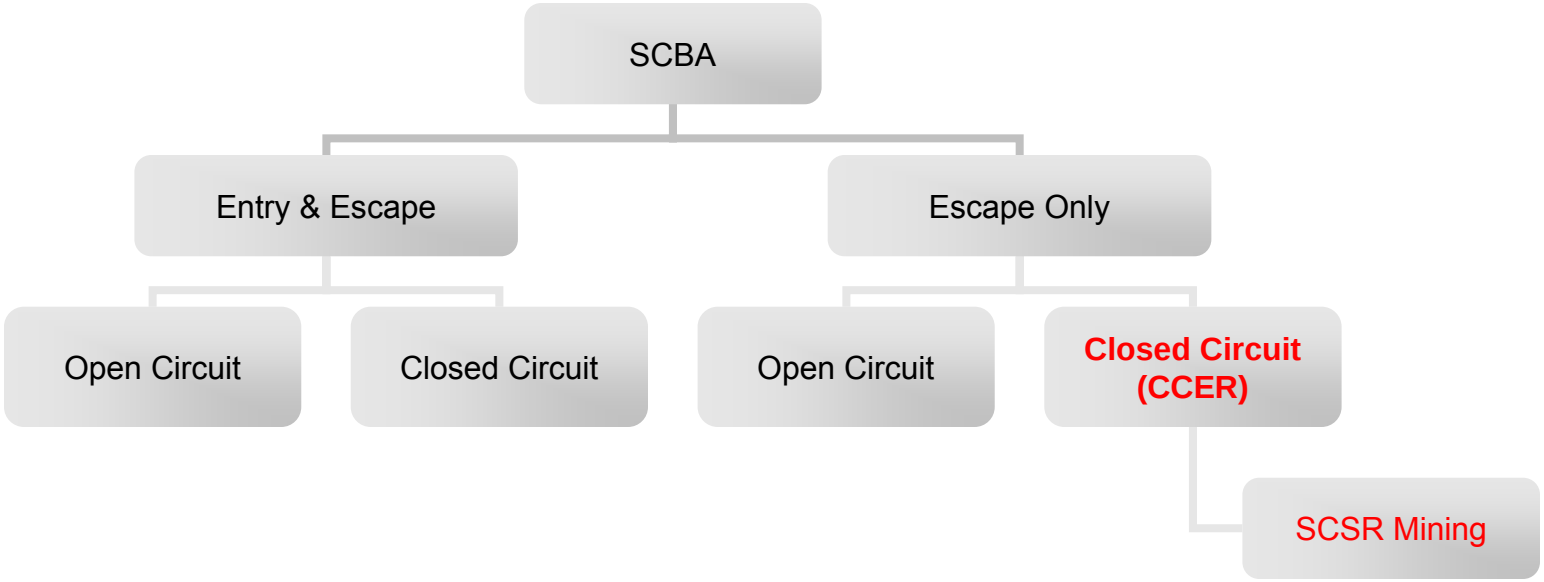
Closed Circuit Escape Respirator (CCER) Meeting

Meeting Purpose

- Present Concepts for Close-Circuit Escape Respirators
  - Breathing and Metabolic Simulators (BMS)
  - Ruggedness and Reliability Concepts
  - Safety Concepts
  - Eye Protection
  - Post Certification Testing
  - Registration
- CCER Concept Paper on Website
  - http://www.cdc.gov/niosh/npptl/resources/certpgmspt/meetings/091906/090706CCERconcept.pdf

Terminology

42 CFR, Part 84 Subpart H Self-Contained Breathing Apparatus



- **CCER = Closed Circuit Escape Respirator**
- **SCSR = Self Contained Self Rescuer = CCER for mining**

NIOSH/NPPTL CCER Public Meeting

The National Institute for Occupational Safety and Health, in consultation with the Mine Safety and Health Administration (MSHA), is in the process of developing a proposed rule on the performance and reliability requirements of close-circuit escape respirators (CCER).

Timeline

- **Public Meetings – Concepts**
  - September 19, 2006 - Arlington, VA
  - September 28, 2006 – Colorado School of Mines
- **Comments to the Docket – November 1st**

Contact Information

Information Docket (Reference Docket # NIOSH 05)

- Mail: NIOSH Docket Office
  Robert A. Taft Laboratories, M/S C 34
  4676 Columbia Parkway
  Cincinnati, OH 45226

- Email: niocindocket@cdc.gov

- Fax: (513) 533-8285

- Phone: (513) 533-8303

- NPPTL Web Site: http://www.cdc.gov/niosh/npptl

Contact Information

- To arrange one-on-one meetings contact
  - Timothy R. Rehak (NIOSH/NPPTL) at:
    - 412.386.6866
    - Email – ter1@cdc.gov

Mine Escape Respirator Program

Comprehensive program to advance mine escape respirator technology

- Provide respiratory protection with increased capacity (duration)
- Reduce physiological burden of escape respirators
- Improve ruggedness and durability of escape respirators
- Improve the capability to provide realistic training

Mine Escape Respirator Program

Program components:

- New Technology Workshops
- Evaluation of Deployed Mine Escape Respirators
- Escape Respirator Research
  - Hybrid Escape Respirator Research
  - Dockable Escape Respirator Research
- Mine Escape Respirator Training Support
- New Test and Evaluation Requirements

New Technology Workshops

New technology for escape respirators

- Oxygen generation
- Carbon dioxide removal
- Carbon monoxide elimination
- Materials for respirator components
- Materials for storing chemicals and high pressure gasses
- Test technology
- Training methods and materials
- Service and maintenance

New Technology Workshops

- **Collaboration with National Technology Transfer Center (NTTC)**
- **Series of workshops**
  - Two workshops during 2005 (June & December)
  - Third workshop July 2006
  - Fourth workshop planned
- **Innovative and creative approaches for all aspects of mine escape respiratory protection**

Evaluation of Deployed Mine Escape Respirators

Long Term Field Evaluation Program initiated >20 years ago U.S. Bureau of Mines

- Laboratory test to evaluate SCSR performance
- Minimum 200 escape respirators per year
- Annual respirator manufacturer quality site audits
- Annual report

Hybrid Self Rescuers

Hybrid Self Rescuer (HSR): Combination SCSR and FSR Respirator

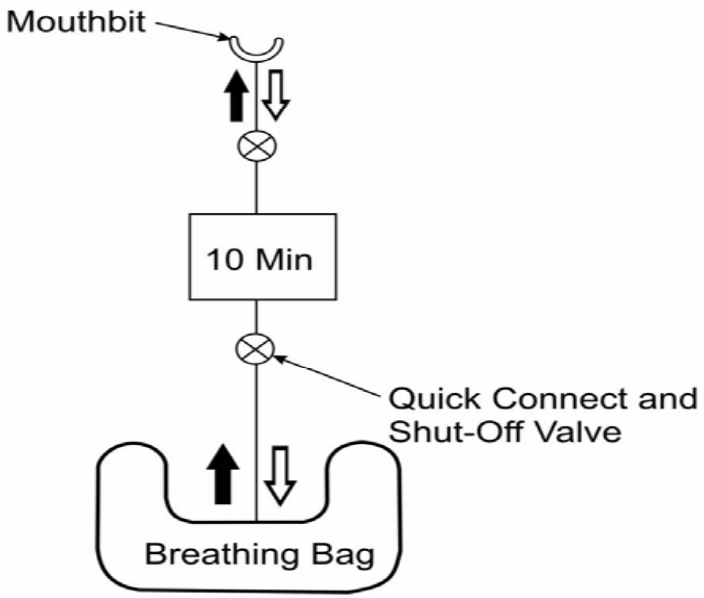
- Operation
  - SCSR
    - O_2 Supply & CO_2 Removal
    - KO_2 , Chlorate or Compressed Gas
  - FSR
    - Traditional Technology → Hopcalite for CO removal
    - New Technology → CO Oxidation Catalysts is encouraged
- Advantages
  - Extended Protective Capacity
- Challenges
  - Sensing CO & O_2
  - Switching → Mode of Operation

Dockable Self Rescuers

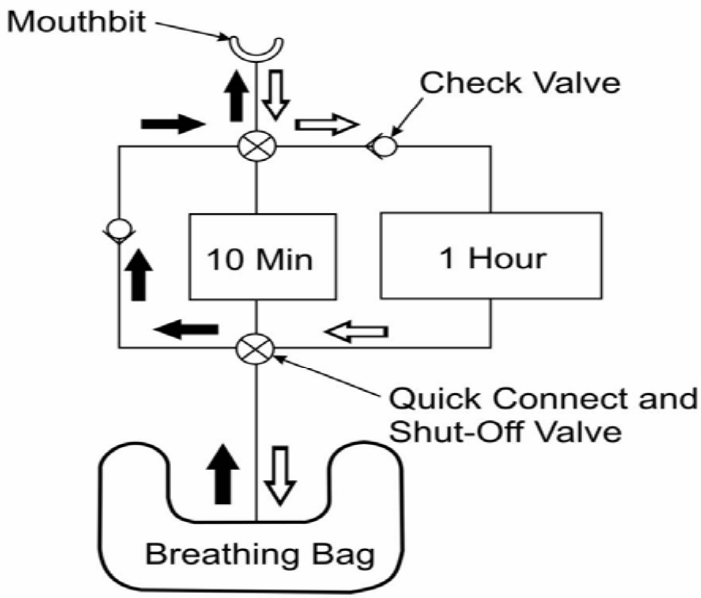
Dockable Short & Long Duration SCSR

- Operation
  - Chemical Based, or
  - Compressed Gas
- Advantages
  - Eliminates Multiple Donnings – breathing circuit not compromised
  - Extended Protective Capacity
  - Allows for Smaller, Lighter Carried SCSR
- Challenges
  - Docking operation in contaminated atmosphere
  - Maintain breathing circuit
  - Reliability of mechanism / operation

Schematic Dockable SCSR



SHORT DURATION SCSR



COUPLED SHORT AND
LONG DURATION SCSR

Escape Respirator Training Support

- **Collaboration with MSHA**
- **Develop training modules on inspection, care & use**
- **Update training modules for multiple donning**
- **Support MSHA with SCSRs for live training**

New Evaluation Concepts

- **Topic for public meeting**
  - Closed Circuit Escape Respirator (CCER)
  - Evaluation Concepts for NIOSH/MSHA Certification
- **Previous public meeting - 2003**
- **Staff level work to prepare rulemaking data for CCER evaluation concepts**
- **Reintroduce concepts development via public meetings and comments**

Wrap Up

Closed-Circuit Escape Respirators (CCER)
Proposed Concepts

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SCSR History

CCER Public Meeting
19 September 2006

SCSR History

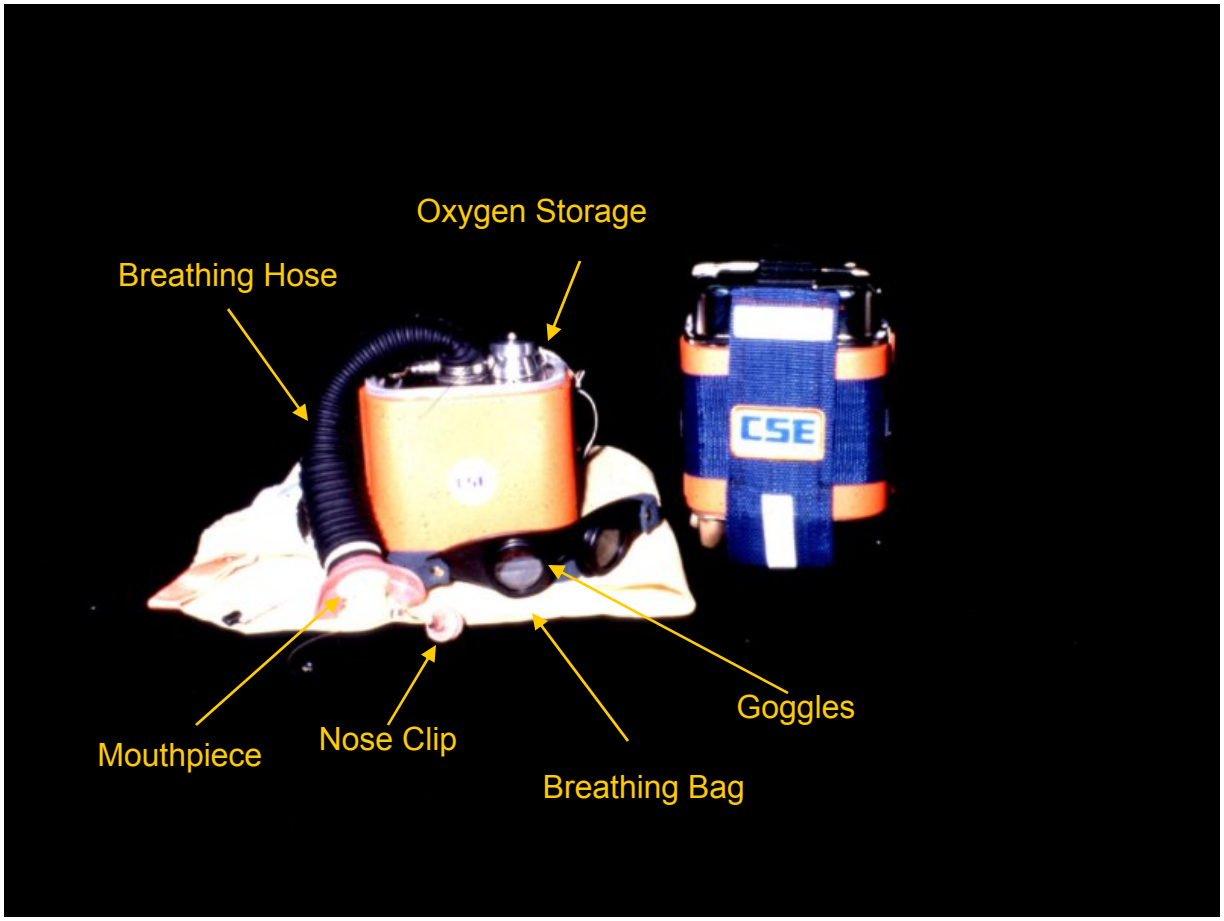
- **Pre-1981 miners rely on FSRs**
- **1981 1st generation SCSRs**
  - Joint MSHA/NIOSH approval under 30 CFR 11
  - MSHA (30 CFR 75.1714)
- **1983 LTFE begins (50/year)**
- **1989 2nd generation SCSRs**
  - Smaller, lighter weight
- **2001 NPPTL Established**
  - LTFE expands
    - 200 SCSRs/phase
- **2003 – Concepts developed for New SCSR Requirements**
- **NTTC Workshops (June 05, December 05, July 06)**
- **2006 MSHA Emergency Temporary Standard**
- **2006 Miner Act**
- **2006 – Request for Proposals Released**
  - Dockable SCSR
  - Hybrid SCSR

Lessons Learned From The 25 Year History Of SCSRs

- **Escape is the primary survival strategy.**
- **In some cases more than 1 SCSR per miner is needed for escape.**
  - 1 hr SCSR does not mean 1 hr for every miner under every circumstance
  - Actual duration depends upon
    - Miner – body weight , age, physical fitness
    - Difficulty of the escape – distance, escapeway factors

MSHA/NIOSH Approved SCSRs

SCSR Components

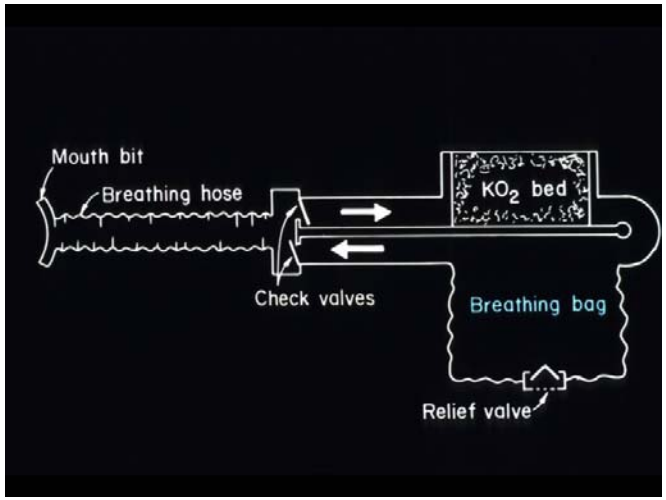


Self Contained Self Rescuer Operation

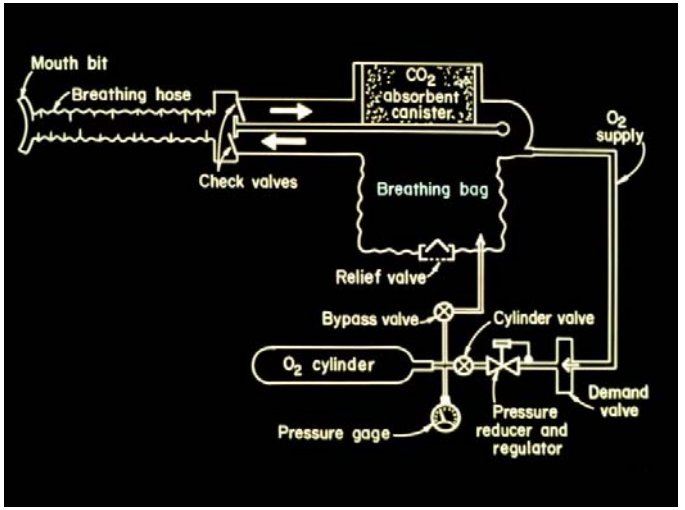
- **Chemical Based Systems**
  - Potassium Superoxide
  - CO_2 Removal
  - O_2 Generation
- **Compressed Oxygen Systems**
  - Compressed O_2 Supply
  - Chemical CO_2 Removal (LiOH)

How An SCSR Works

Chemical Oxygen



Compressed Oxygen



Partnerships

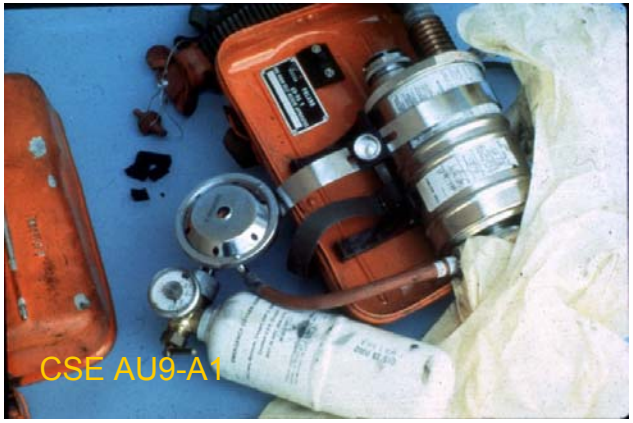
- **Stakeholders**
  - BCOA
  - NMA
  - UMWA
  - USWA
  - U.S. Navy
  - SCSR manufacturers: CSE, Draeger, MSA, and Ocenco
- **MSHA is co-approver**

Long-Term Field Evaluation (LTFE)

LTFE Publications

Pub #	Published	Test dates	Results
RI9051	1986 pub	First year of a 5 year program	
RI9401	1992 pub	Testing 82-90	Phase 1, 2, and 3
RI9499	1994 pub	Testing 89-93	Phase 4
RI9635	1996 pub	Testing Mid-93 to Early-96	Phase 5
IC 9451	2000 pub	Testing Mid-96 to early 98	Phase 6
RI9656	2002 pub	Testing May 99 – Aug 00	Phase 7
	in review	Testing Dec 00 - Apr 02	Phase 8
	in review	Testing Jun 02 - Apr 04	Phase 9

SCSRs (1st Generation)



SCSRs (2nd Generation)


SR-100


OXY K PLUS


Life Saver 60


EBA 6.5

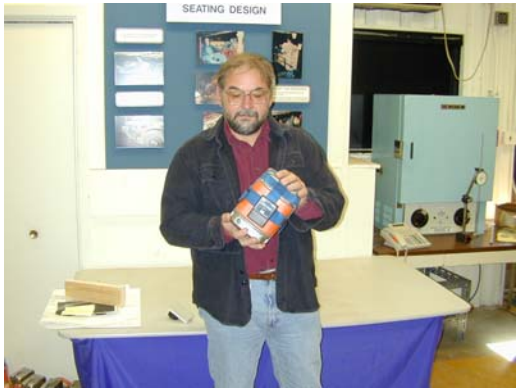

M-20

Non-Destructive Tests

High Temperature

CSE

Bed Degradation



CSE

Draeger

LTFE Conclusions

- **SCSRs that pass inspection criteria should provide for safe life support**
- **Some performance degradation observed in all apparatus**

LTFE Protocol

- **Objective**
  - Compare the performance of deployed SCSRs to new SCSRs.
- **Method**
  - Collection inspection
  - Sample
  - Replace
  - Laboratory inspection
  - Test
- **Report**
  - LTFE Report
  - Investigation reports

LTFE Testing

BMS

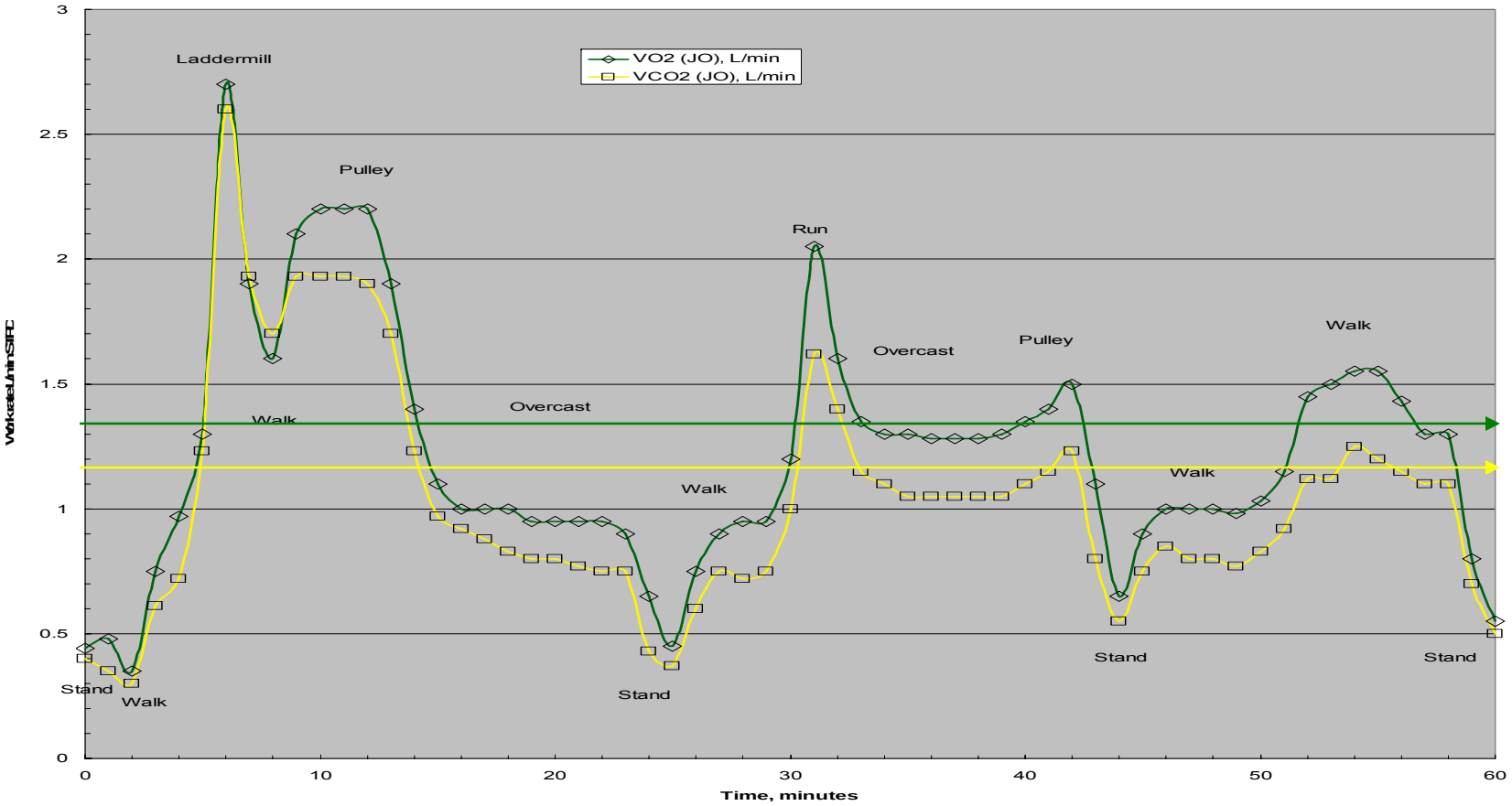
Man Test -Treadmill

Metabolic workload	BMS	Treadmill
O_2 consumption rate L/min.	1.35	1.35
CO_2 production rate L/min.	1.15	*
Ventilation rate L/min.	30.0	*
Tidal volume L/breath	1.68	*
Respiratory frequency breaths/min.	17.9	*
Peak respiratory flow rate:		
Inhalation L/minute	89	*
Exhalation L/minute	71	*
* Pace of treadmill test is set to maintain oxygen consumption at the stated rate.		

NIOSH Certification Testing Man Test #4

- **Test which assigns rated duration.**

Man Test #4 Metabolic Load



LTFE Data and Results

- The purpose of the LTFE is to obtain data to compare the performance of deployed to new SCSRs.
- Evaluations are based on experimental protocols not certification standards
- Test methods, protocols and results are not substitutes for nor superior to 42 CFR 84
- Process of discovery
  - Not based on a random sample
  - Discover problems that the existing standard may not have anticipated
  - Compare new to field deployed SCSRs
  - Practical improvements
- Results
  - Test results alone do not predict successful use in a mine escape

Reliability

- **Reliability = Will my SCSR work?**
  - How has it been handled?
  - How old is it?
- **Reliability = When should an SCSR be removed from service?**
  - Are the inspection criteria sound?
  - Are users well trained to inspect?

Actions

- **Inspect all field deployed SCSRs**
  - Remove non-conforming units from service
- **Voluntary Registration**
  - NPPTL Web-based model
- **Training**
  - Multiple donning
  - Training with “live” apparatus
- **Expanded LTFE**
  - Link LTFE to CPIP and Site Audits
  - Timely outcomes

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Applicable Sections of 42 CFR Part 84

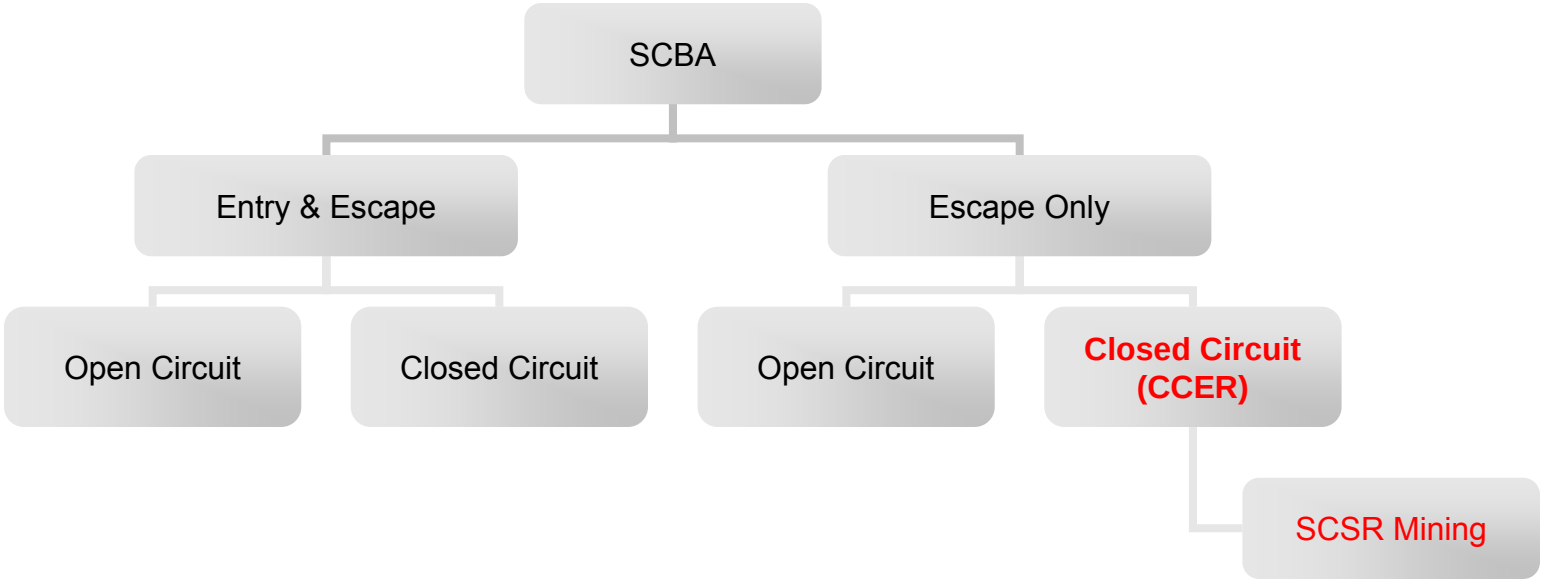
- Subpart A – General Provisions (entire subpart)
- Subpart B – Application for Approval (entire subpart)
- Subpart C – Fees (entire subpart)
- Subpart D – Approval and Disapproval (entire subpart)
- Subpart E – Quality Control (entire subpart)
- Subpart F – Classification of Approved Respirators; Scope of Approval; Atmospheric Hazards; Service Time – Paragraphs 84.50, 84.51, and 84.52
- Subpart G – General Construction and Performance Requirements (entire subpart)

CCER Concepts

- Description
- Applicability to new and previously approved CCERs
- Required components, attributes, and instructions
- General testing conditions and performance concepts
- Capacity tests
- Performance tests
- Wearability tests
- Environmental treatments
- Additional testing
- Post-certification testing
- Voluntary Registration

Terminology

42 CFR, Part 84 Subpart H Self-Contained Breathing Apparatus



- **CCER = Closed Circuit Escape Respirator**
- **SCSR = Self Contained Self Rescuer = CCER for mining**

Technical Improvements

- **Research**
- **Long Term Field Evaluation (LTFE)**
- **Certification**
- **Certified Product Investigation Program (CPIP)**

Components, Attributes, and Instructions

- **Components**
  - NDT
  - Tamper-resistant/tamper-evident casing
  - Eye protection
- **Attributes**
  - Meet the general construction requirements of 42CFR84
  - Must not constitute a hazard
- **Instructions**
  - Hands–on Training
  - Service Life

General Testing Conditions and Performance Concepts

- **Breathing and metabolic simulator**
  - Capacity test
  - Performance tests
- **Human subject tests**
  - Used for qualitative evaluations
  - Wearability

General Testing Conditions and Performance Concepts

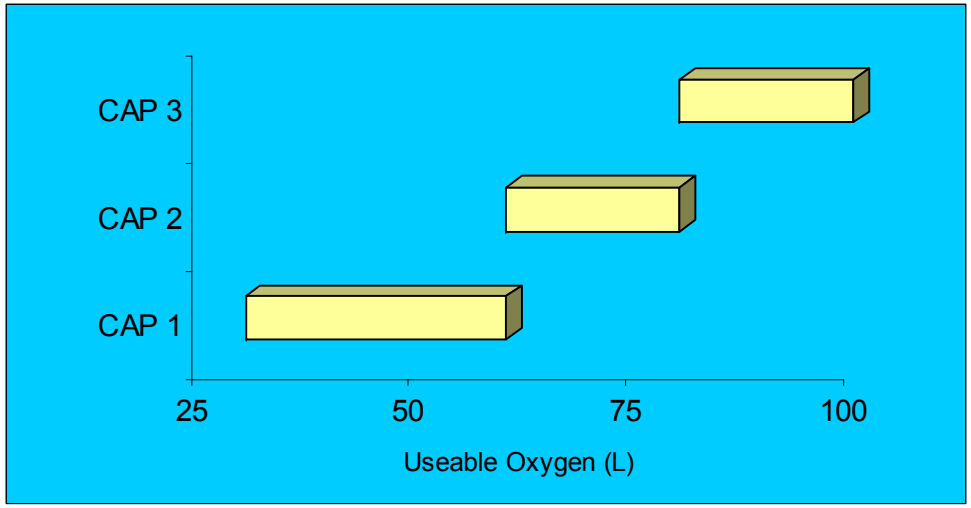
Stressor	Acceptable Range Operating Average	Acceptable Range Excursion
Average inhaled CO_2	<1.5%	≤4%
Average inhaled O_2	>19.5%	≥15%
Peak breathing pressures	$\Delta P \leq 200$ mm H_20	$-300 \leq \Delta P \leq 200$ mm H_20
Wet-bulb temperature	<43°C	≤50°C

Proposed Capacity Tests

- Tests
  - Continuously Monitored
    - Breathing and metabolic simulator (BMS)
    - BMS after environmental treatments
    - Human subject on a treadmill
- Cap 3 rating for mining SCSRs
  - 2 each – one-hour Man Test 4

Capacity Test Concepts

Capacity Rating	Capacity (L)	O_2 (L/min)	CO_2 (L/min)	Ve (L/min)	RF (Breaths/min)
Cap 1	$30 \leq L \leq 59$	2.50	2.50	55	22
Cap 2	$60 \leq L \leq 79$	2.00	1.80	44	20
Cap 3	$L \geq 80$	1.35	1.15	30	18

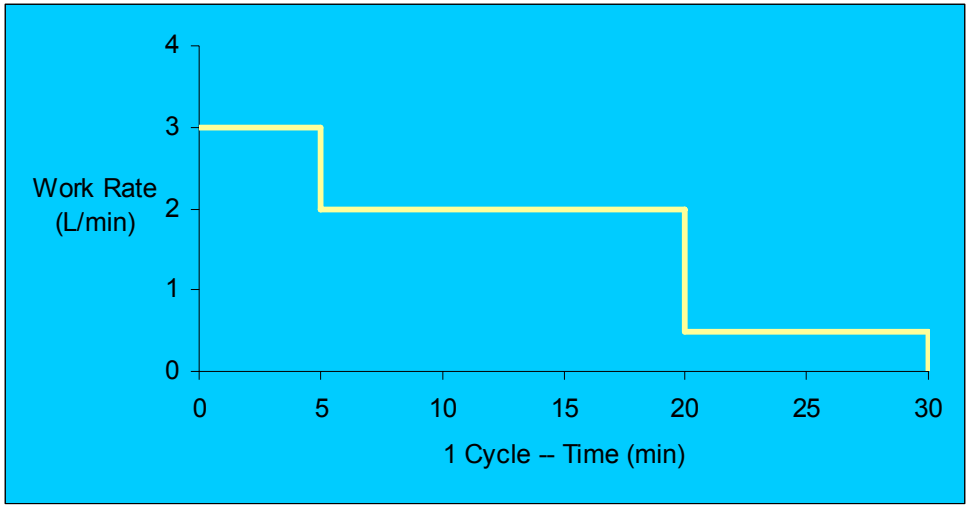


Proposed Performance Tests

- **Tests**
  - Variable work rates
  - Continuously monitored
    - BMS
    - BMS after environmental treatments
    - Human subject on treadmill

Performance Test Concepts

Work-Rate Test Sequence	Duration per cycle	O_2 (L/min)	CO_2 (L/min)	Ve (L/min)	RF (breaths/min)
1. Peak	5 min.	3.00	3.20	65.0	25
2. High	15 min.	2.00	1.80	44.0	20
3. Low	10 min.	0.50	0.40	20.0	12



Wearability Test Concepts

- Ensure the CCER can be easily and quickly donned.
- Ensure that, during any reasonably anticipated activity, the CCER:
  - Will not physically harm the user,
  - Will not significantly hinder the user,
  - Will provide an adequate and uninterrupted supply of breathing gas.

Activity	Minimum Duration
Sitting	1 min.
Stooped walking	1 min.
Crawling	1 min.
Lying on left side	1 min.
Lying on right side	1 min.
Lying on back	1 min.
Bending over to touch toes	1 min.
Turning head from side to side	1 min. (at least 10 times)
Nodding head up and down	1 min. (at least 10 times)
Climbing steps or a laddermill	1 min. (1 step/sec)
Carrying 50-lb bag on treadmill at 5 kph	1 min.
Lifting 20-lb weight from floor to an upright position	1 min. (at least 10 times)
Running on treadmill at 10 kph	1 min.

Proposed Environmental Treatments

- Four units will be tested for capacity and performance - post treatment
- Treatments:
  - Extreme temperatures
    - 16-hours at -45°C
    - 48-hours at 71°C
  - Physical shock – dropped from a height of 1-meter on each axis
  - Vibration – 180 minutes along each axis
    - MIL Spec 810

Proposed Additional Testing

- Safety hazard tests (15 additional new units) on apparatus that:
  - Stores more than 200 liters of oxygen
  - Stores compressed oxygen at pressures exceeding 3,000 psi
  - Bureau of Mines
- Eye protection:
  - Dust – ISO 4855, Clause 13
  - Gas – ISO 4855, Clause 14
  - Durability – ISO 4855, Sub-Clause 3.1
  - Fogging - EN 168: 2000

Proposed Post-Certification Testing

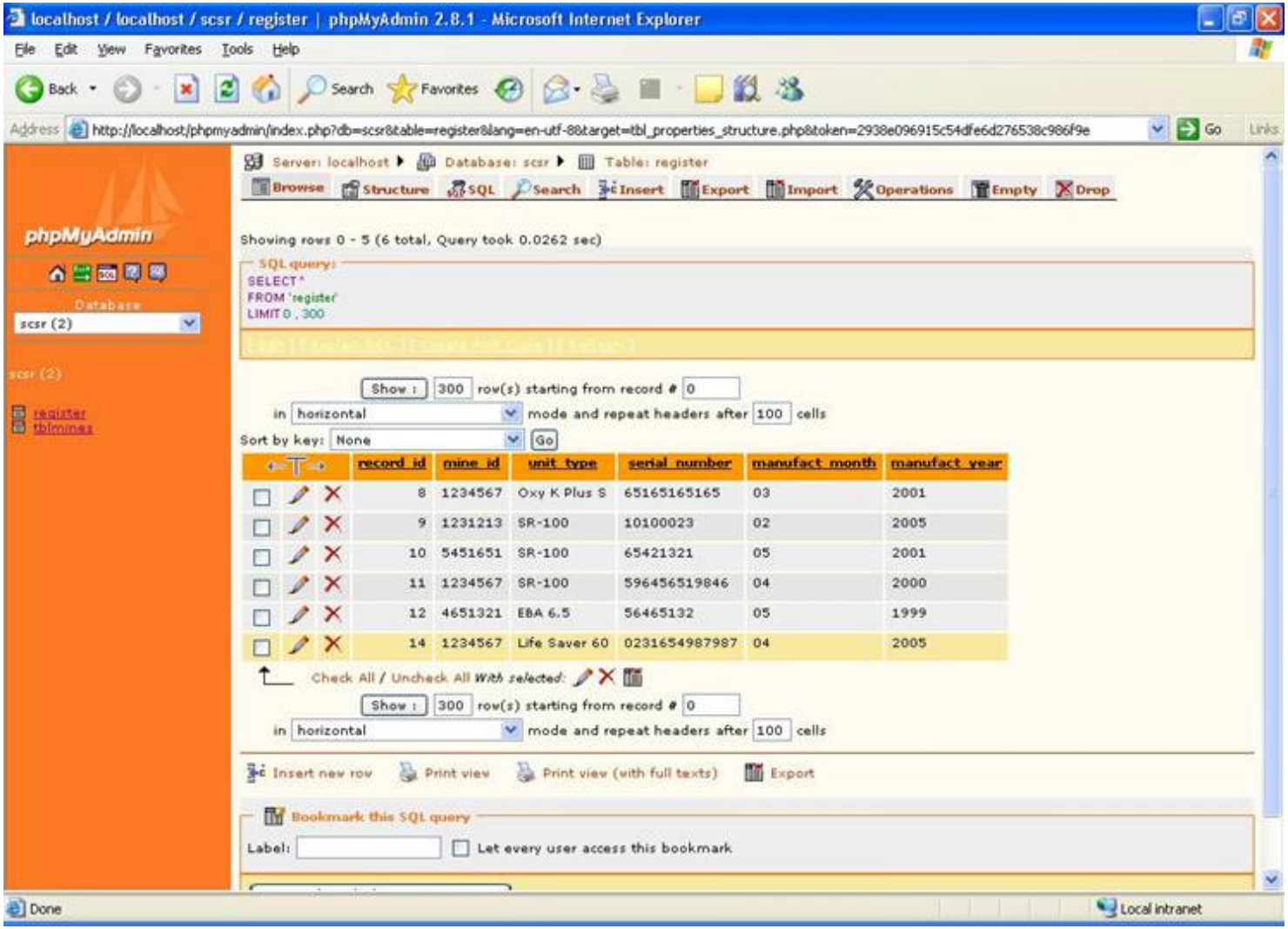
- Test new and deployed for capacity and performance
- Failure may result in revocation of approval or remedial actions
- NIOSH will replace deployed units obtained for testing
- Approval holder must make units available for purchase

Proposed Voluntary Registration

- **Purpose**
  - To provide information on numbers and locations
- **Support post certification testing and evaluation**
  - LTFE sampling
- **Basis for quick and effective reaction to field complaints**
  - Risk communication
  - Recalls
- **Manufacturer required to:**
  - Provide procedures
  - Purpose

Proposed Registration Website

Registration Spreadsheet



Propose Applicability to New and Previously Approved CCERs

- **Manufacturers and distributors can continue to sell CCERs with current approvals for 3 years.**
- **CCERs with current approvals can remain in use for 6 years.**

A Review of Self-Contained Self-Rescuer Research

Arthur T. Johnson, Ph.D.

Professor, Biological Resources Engineering Dept.

Self-Contained Self-Rescuer (SCSR)

- Provides oxygen for emergency escape

- Supposed to supply at least 60 minutes of oxygen

- **CSE SR-100**
  - Contains Potassium Superoxide (KO_2)
  - Chemical reaction that generates oxygen from moisture in exhaled breath (H_2O)

$$2KO_2 + H_2O \rightarrow 2KOH + 1.5O_2$$

  - Carbon Dioxide (CO_2) from exhaled breath reacts to form more water vapor, which reacts to form additional oxygen

$$2KOH + CO_2 \rightarrow K_2CO_3 + H_2O$$

- SCSR wearers are required to walk at a controlled pace so oxygen supply does not outpace the rate of oxygen use

- Enough oxygen is supplied to keep up with the rate of work **IF** **breathing air** is **proportional** to **oxygen demands**

- **What happens at high work rates?**
  - Breathing air is disproportionate to oxygen usage rate
  - Oxygen generating capacity is used up at a much faster rate
  - Extra oxygen is wasted to atmosphere

Two UMD Studies

1) How Far Can One Walk Wearing a Self-Contained Self-Rescuer?

- **Goal:** Determine the distance that can be walked when using SCSRs as intended

- **Discovered:**
  - Average Distance = 3.7 miles
  - Allows estimable distance to place additional SCSRs on route

2) Using Self-Contained Self-Rescuers at High Work Rates

- **Goal:** Examine effect of exercise intensity on performance time while wearing CSE SR-100

- **Discovered:**
  - SCSRs used outside of recommended range incur severe penalties

How Far Can One Walk Wearing a Self-Contained Self-Rescuer?

60 minutes of oxygen = what distance?

Answer (average result):

6.0 km (3.7 miles)

- 14 volunteer subjects
- PAR-Q health assessment form
- Maximum oxygen uptake in range of average fitness levels (2.7-3.2 L/min)
- Treadmill walking, 0% Grade
- Speed determined by subjects (had to meet rate of oxygen supplied)
- Instructed to walk as long as possible


CSE
CORPORATION
TRAINING UNIT
TRAINING

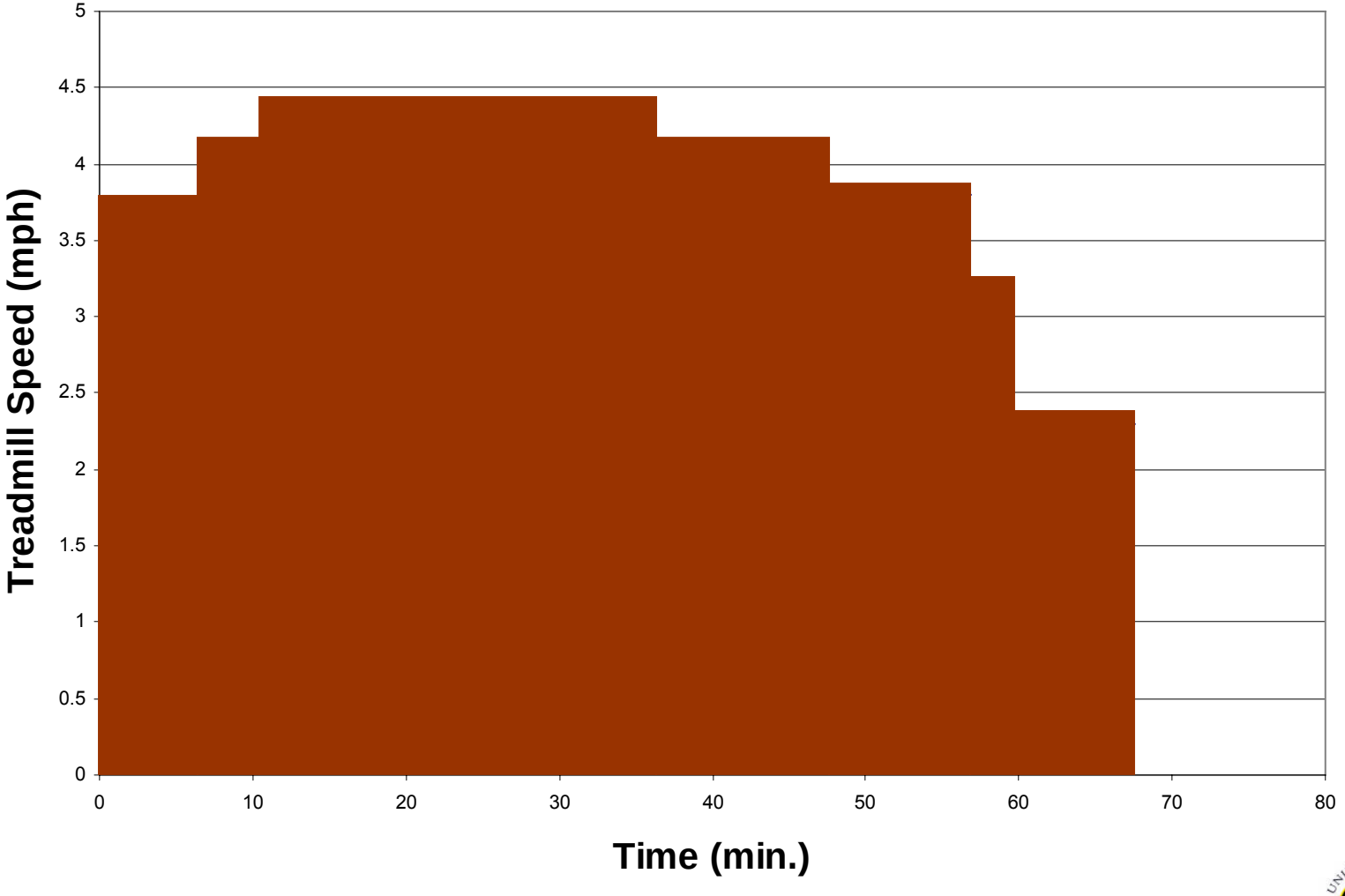
- **Results**
  - Distances
    - **Maximum** distance obtained = **9.2 km** (5.7 miles)
    - **Minimum** distance obtained = **2.1 km** (1.3 miles)
    - **Average** of **6.0 km** (3.7 miles)

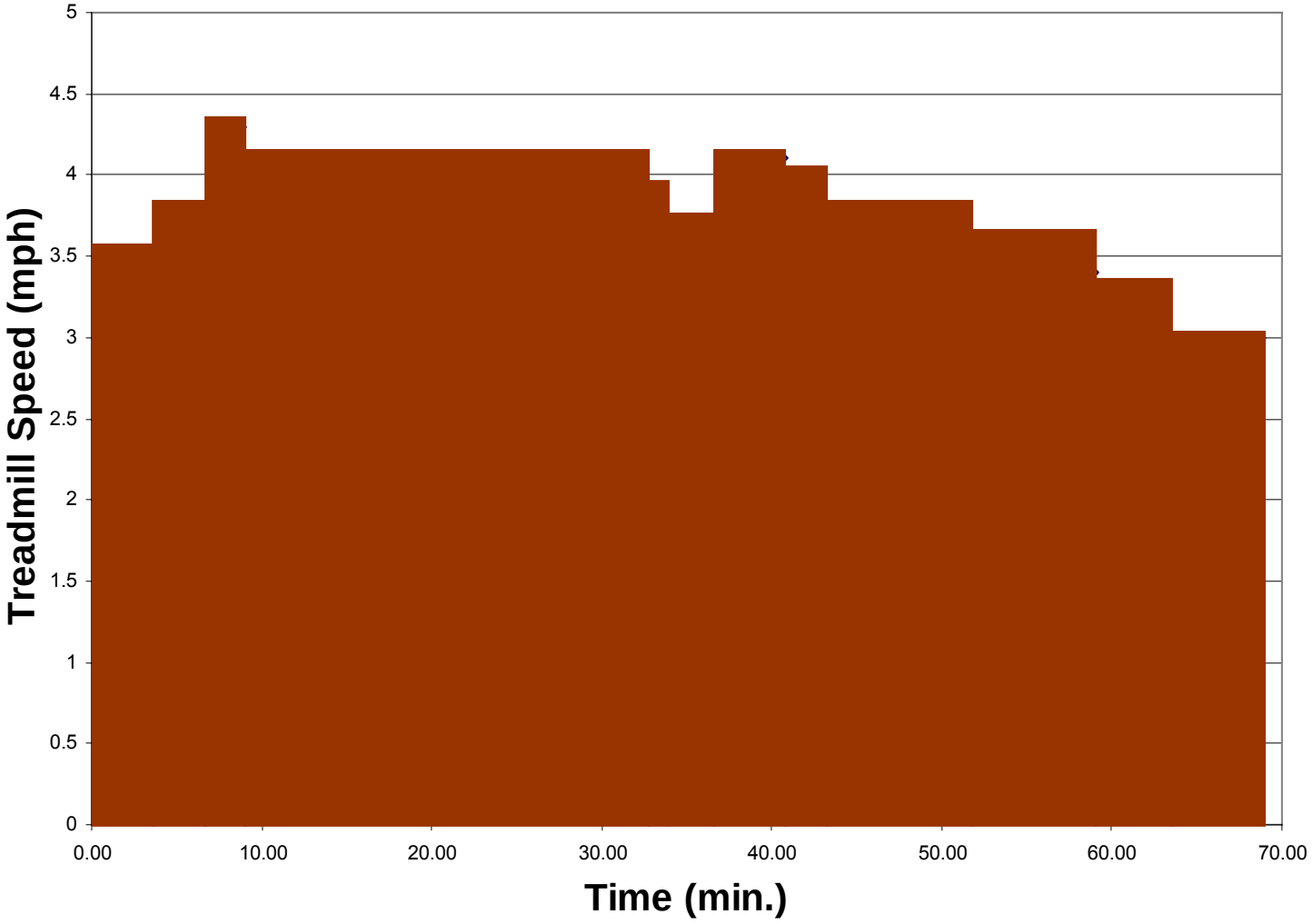
- **Results** ***(cont'd)***
  - Times
    - 30 minutes to 94 minutes
    - **Average** of **65 minutes**

Subject Performance Data

Subject	Time (min)	Distance (miles)	Termination Reason
1	57	2.9	insufficient air
145	59	3.5	none given
292	50	2.4	insufficient air
340	73	4.4	difficult to inhale
343	69	4.2	air too hot
358	67	4.3	air too hot
401	46	3	none given
402	75	4.2	none given
404	71	4.7	none given
406	30	1.3	insufficient air
409	69	3.7	difficult breathing
410	81	3.4	air too hot
411	90	5.6	difficult breathing
412	94	5.1	insufficient air
Avg.	65	3.7	

- **Results** ***(cont'd)***
  - Speeds
    - Began at 1.3 m/sec (3.0 mph) and adjusted for each subject
    - Found no correlation between speed and distance walked


Treadmill Speed (mph)
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0
10
20
30
40
50
60
70
80
Time (min.)


Treadmill Speed (mph)
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
Time (min.)

- **Subject Complaints (SR-100)**
  - Unit gets very hot
  - Inhaled air uncomfortably warm
  - Inhaled fine, gritty material
  - High resistance toward end
  - Difficulty keeping nose clip on
  - Mouthpiece uncomfortable

- **Conclusion**
  - Additional SCSRs should be stationed at locations along route
  - Extra SCSRs should be available to carry from the beginning of the escape

- **Conclusion** ***(cont'd)***
  - Training is very important
    - Potential wearers should know about device limitations
    - Potential wearers should practice with the units
      - Become familiar with SCSR and aware of complaints listed
      - Additional practice would increase performance times and distance

Using Self-Contained Self-Rescuers at High Work Rates

With controlled pace walking, oxygen should be available for 60 minutes.

What happens…

High Speeds = X minutes Oxygen??

- One volunteer subject, $\dot{V}O_2 \max = 3.0 L/\min$
- Treadmill walking, 0% Grade
- Five testing sessions, each at varied intensities
  - 65, 70, 75, 80, and 85% $\dot{V}O_2 \max$
- Instructed to exercise until fatigue or until equipment limitations were reached

- **Results**
  - Performance times **decrease linearly** as oxygen consumption increased
  - No performance time reached 60 minutes
  - All work rates were **too high** for SCSR
  - Cause of exercise termination reported to be lack of supply from SCSR

Experimental Data

% VO2 Max	Performance Time (min)	Minute Volume (L/min)
65%	45.7	50
70%	40.5	56
75%	28.4	62
80%	10.4	68
85%	6.5	75

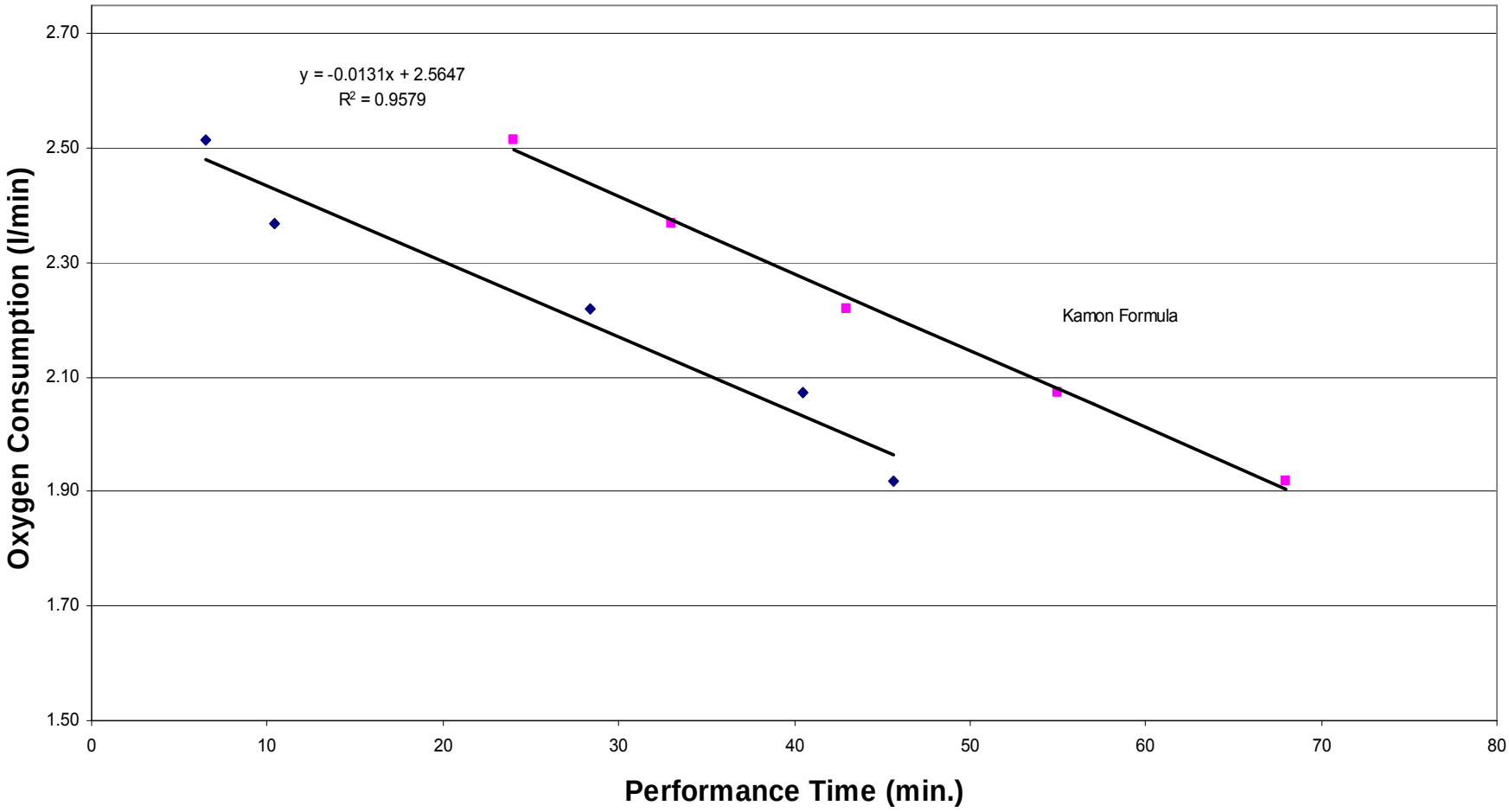
Experimental Data

% VO2 Max	RPE		BACS	
	6 min	term	6 min	term
65%	13	20	5	2
70%	12	19	5	0
75%	15	20	3	0
80%	15	19	2	0
85%	19	20	1	1

- **Calculated Data**
  - **Performance time** (Kamon Formula)

$$t_{\text{perf}} = 120\left(\frac{\dot{V}O_2\,\text{max}}{\dot{V}O_2}\right) - 117$$

  - **Time penalty** = $t_{\text{penalty}} = t_{\text{perf}_{\text{calc}}} - t_{\text{perf}_{\text{meas}}}$
  - **Distance walked** = $(t_{\text{perf}_{\text{meas}}})(\text{treadmill speed})$
  - **Oxygen used** = $(\text{oxygen consumption})(t_{\text{perf}_{\text{meas}}})$


y = -0.0131x + 2.5647
R² = 0.9579
Kamon Formula
Oxygen Consumption (l/min)
2.70
2.50
2.30
2.10
1.90
1.70
1.50
0
10
20
30
40
50
60
70
80
Performance Time (min.)

- **Discussion**
  - **Emergency situation = panic = increased work rates**
  - **Penalty** for increased work rate:
    - SCSR much more uncomfortable
    - Effort more difficult
    - Much lower amount of accessible oxygen
    - Much shorter performance time
  - **Therefore**: **Use SCSR at low rates of work** (oxygen used is matched by oxygen generation)

- **Conclusion**

  – Inverse relationship exists between performance time and exercise intensity

  – Confirmed SCSR must be used as intended

  – Penalty can be expected if SCSR is used outside its range

Overall Conclusion

- In emergency situation, **DON'T PANIC!!!**
- Use SCSR as intended → at **LOW** work rates
- **TRAIN! TRAIN! TRAIN!** Become familiar and aware of SCSR limitations
- Additional SCSRs should be stationed at locations along route

AND/OR

- Extra SCSRs should be available to carry from the beginning of the escape